(12) **EUROPEAN PATENT APPLICATION**

(72) Inventors:
• Nakai, Takehiko
Ohta-ku, Tokyo (JP)
• Setani, Michitaka
Ohta-ku, Tokyo (JP)

(74) Representative:
Pellmann, Hans-Bernd, Dipl.-Ing. et al
Patentanwaltsbüro
Tiedtke-Bühling-Kinne & Partner
Bavariaring 4
80336 München (DE)

(54) **Lens system having diffracting surface and refracting surface and optical apparatus using the lens system**

(57) In a lens system having one or a plurality of diffracting surfaces and one or a plurality of refracting surfaces, a power of each surface and a distance between the surfaces are set such that an optical characteristic of the lens system, such as a focal length (focal point) and/or a spherical aberration, remains substantially unvarying relative to temperature variations within a predetermined range and that an achromatic effect is substantially attained for the focal length (focal point) and/or the spherical aberration within a predetermined region of wavelength.

FIG. 1
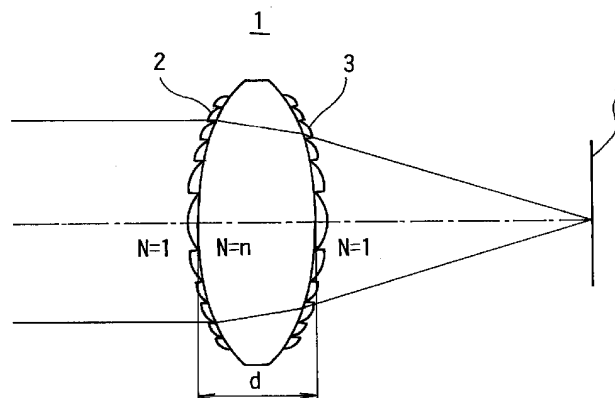
EP 0 840 144 A1

Description

BACKGROUND OF THE INVENTION

5   Field of the Invention

The present invention relates to a lens system having a diffracting surface and a refracting surface, and more particularly to a lens system advantageously adapted for the image forming optical system of an optical apparatus such as an interchangeable lens, a camera, a copying apparatus, a semiconductor-device-manufacturing exposure device, a
10   microscope, a binocular, a telescope, an optical recording/reproducing apparatus, a projector, or the like.

Description of Related Art:

In a lens system in which a material having a high thermal expansion coefficient, such as a plastic material, is used
15   for a lens, variations in temperature cause a change in refractive index of the material and also cause the material to expand or contract to change the shape of the lens. The optical characteristics of the lens system would be affected by the temperature variations if such changes are left uncorrected. Therefore, it is necessary to have some correcting means. To meet this requirement, it is usual to prestore in a memory or the like the amounts of changes in optical characteristics (such as focus, etc.) anticipated to be caused by temperature variations, have a temperature sensor
20   arranged in the vicinity of the lens, and make necessary correction by reading an applicable amount of change of the optical characteristics due to the temperature variations from the memory in accordance with the output of the temperature sensor (corresponding to the amount of change of temperature or to the temperature). However, this correcting method necessitates the use of additional means such as the temperature sensor and the memory, thereby causing an increase in cost of the lens system. To solve that problem, a method of arranging the lens system itself to be capable
25   of correcting changes of optical characteristics due to temperature variations without using such correcting means has been developed, for example, as disclosed in U.S. Patent No. 5,260,828. According to U.S. Patent No. 5,260,828, a diffracting optical system (diffracting surface) such as a kinoform or the like and a refracting optical system (refracting surface) such as an ordinary lens are combined with each other in such a way as to have temperature characteristics opposite to each other.
30   In the lens system which is formed by combining the diffracting optical system and the refracting optical system, the color dispersion characteristic of the refracting optical system is inverse to that of the diffracting optical system. Therefore, it is known that an achromatic effect (achromatism) can be attained by arranging the power of the diffracting optical system (1/"focal length") to be of the same sign as that of the power of the refracting optical system (1/"focal length").
35   However, according to the specification of the above-mentioned U.S. Patent No. 5,260,828, a relation obtained between the diffracting optical system and the refracting optical system in correcting variations of optical characteristics caused by variations in temperature is as follows. 1) The power of the diffracting optical system is at least 20% in absolute values. 2) In a plastic-used lens system, the power of the diffracting optical system is either larger than the power of the refracting optical system or of opposite sign.
40   Further, according to the specification of the above-mentioned U.S. Patent No. 5,260,828, the relation between the diffracting optical system and the refracting optical system to be arranged for achromatism, i.e., in attaining an achromatic effect, is as follows. The power of the diffracting optical system is less than 15% in absolute values, and the power of the diffracting optical system is smaller than the power of the refracting optical system and of the same sign.
As mentioned above, the lens system formed by combining the diffracting optical system and the refracting optical
45   system, as disclosed in U.S. Patent No. 5,260,828, is arranged to do nothing for achromatism while correcting the variations of optical characteristics caused by temperature variations. In that lens system, therefore, a chromatic aberration inevitably takes place, thereby lowering the performance of the lens system.

BRIEF SUMMARY OF THE INVENTION
50
It is an object of the invention to provide a lens system having a high rate of performance and an optical apparatus using the lens system.
In accordance with an aspect of the invention, there is provided a lens system having one or a plurality of diffracting surfaces and one or a plurality of refracting surfaces, in which a power of each surface and a distance between the sur-
55   faces are set such that an optical characteristic of the lens system, such as a focal length (focal point) and/or a spherical aberration, remains substantially unvarying relative to temperature variations within a predetermined range and that an achromatic effect is substantially attained for the optical characteristic (the focal length (focal point) and/or the spherical aberration) within a predetermined region of wavelength.

Further, in accordance with another aspect of the invention, there is provided a lens system having one or a plurality of diffracting surfaces and one or a plurality of refracting surfaces, in which a power of each surface and a distance between the surfaces are set such that an optical characteristic of the lens system, such as a focal length (focal point) and/or an amount of spherical aberration, remains the same at two different temperatures and that the optical characteristic (the focal length (focal point) and/or the amount of spherical aberration) remains the same at two different wavelengths.

Further, in accordance with a further aspect of the invention, there is provided an optical apparatus using one of the above-stated lens systems as an image forming optical system, in which the optical apparatus is an interchangeable lens, a camera, a copying apparatus, a semiconductor-device-manufacturing exposure device, a microscope, a binocular, a telescope, an optical recording/reproducing apparatus, a projector or the like.

The above and other objects and features of the invention will become apparent from the following detailed description of embodiments thereof taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

Fig. 1 shows a lens system arranged according to the invention as an embodiment thereof.

Fig. 2 shows by way of example how the power of the lens system shown in Fig. 1 varies in relation to variations of wavelength.

Fig. 3 shows by way of example how the power of the lens system shown in Fig. 1 varies in relation to variations of temperature.

Fig. 4 shows a lens system arranged according to the invention as another embodiment thereof.

Fig. 5 shows by way of example how the power of the lens system shown in Fig. 4 varies in relation to variations of wavelength.

Fig. 6 shows by way of example how the power of the lens system shown in Fig. 4 varies in relation to variations of temperature.

DETAILED DESCRIPTION OF THE INVENTION

Hereinafter, preferred embodiments of the invention will be described in detail with reference to the drawings.

Fig. 1 shows a first embodiment of the invention. In the first embodiment shown in Fig. 1, a lens system is composed of a single lens, for the sake of simplification of illustration. However, the lens system of course may be changed to include two or more lenses, instead of just one. In Fig. 1, reference numeral 1 denotes a hybrid lens system composed of a diffracting optical system and a refracting optical system. A light flux incident on the lens system 1 is bent to a certain degree of angle at a first surface 2 having a diffracting surface, by a diffracting action of the diffracting surface and also by a refracting action of the curvature of a convex surface of the base of the lens system 1. Then, after passing through the material of the base of the lens system 1, the light flux is bent at a second surface 3 having a diffracting surface, by a diffracting action of the diffracting surface and a refracting action of the curvature of another convex surface of the base of the lens system 1. The light flux is thus caused to converge on a focal plane 4. In Fig. 1, the diffracting surface is illustrated exaggeratedly in a deformed shape in an optical axis direction. In actuality, letting a wavelength as a datum be denoted by λ_0 and a refractive index obtained at the wavelength λ_0 of the material which forms the diffracting surface (diffraction grating) be denoted by n_0, the depth h in the optical axis direction of the diffraction grating can be expressed as follows:

$$h = \frac{m\lambda_0}{(n_0-1)} \text{ (m being a positive number).}$$

If the value m is assumed to be 1, the datum wavelength λ_0 to be 540 nm and the refractive index n_0 to be 1.49409, the depth h is 1.092 μm. Incidentally, a diffraction grating which forms the diffracting surface of each of the first surface 2 and the second surface 3 of the lens system 1 has a finite power (1 / "focal length")

Referring to Fig. 1, the power of the diffracting surface of the first surface 2 is assumed to be ϕ_a and the curvature of the base at the first surface 2 is assumed to be r_1. Then, assuming that the light entrance side of the first surface 2 is air, a refractive index N of which is 1, and the base is a material whose refractive index N is n, a power ϕ_1 of the refracting optical system of the first surface 2 can be expressed as: $\phi_1 = (n - 1) / r_1$. Since, in the first surface 2, the diffracting surface and the refracting surface exist on a common surface with a distance between them at "0" in this instance, a composite power ϕ_{1a} of the first surface 2 can be expressed as $\phi_{1a} = \phi_a + \phi_1$. In the similar way, the power of the diffracting surface of the second surface 3 is assumed to be ϕ_b and the curvature of the base at the second surface 3 is assumed to be r_2. Then, assuming that the light exits into air of the refractive index N = 1 from the material of

3

the refractive index $N = n$, a power ϕ_2 of the refracting optical system of the second surface 3 can be expressed as $\phi_2 = (1 - n) / r_2$. Then, since, in the second surface 3, the diffracting surface and the refracting surface exist on a common surface with a distance between them at "0", a composite power ϕ_{2b} of the second surface 3 can be expressed as $\phi_{2b} = \phi_b + \phi_2$. A distance between the first surface 2 and the second surface 3 is assumed to be "d" and to be filled with the material of the refractive index "n" as mentioned above.

Here, the concrete construction of the lens system 1 will be described by way of example. The base of the lens system 1 is made of a PMMA (polymethyl methacrylate), which is a kind of plastic material, to perform an achromatic action with respect to wavelengths 540 nm and 610 nm and to have no variation take place in the power of the entire lens system as an optical characteristic within a range of temperature variation amount of 20 degrees.

The characteristics of the PMMA used for the base of the lens system 1 are first described as follows. The refractive indices n_0 and n_1 of the PMMA obtained respectively at wavelengths 540 nm and 610 nm are 1.49409 and 1.49078 (n_0 = 1.49409 and n_1 = 1.49078). Further, the coefficient of linear expansion α of the PMMA is $\alpha = 6.74 \times 10^{-5}$, and the refractive index variation $\frac{dn}{dt}$ of the PMMA due to temperature variations is expressed below:

$$\frac{dn}{dt} = -11.5 \times 10^{-5}.$$

Here, the power ϕ_T of the entire lens system 1 can be expressed as follows:

$$\phi_T = \phi_{1a} + \phi_{2b} - \frac{d}{n}\phi_{1a} \cdot \phi_{2b} \tag{1}.$$
$$= (\phi_a + \phi_1) + (\phi_b + \phi_2) - \frac{d}{n}(\phi_a + \phi_1) \cdot (\phi_b + \phi_2)$$

Assuming that the powers of elements obtained at the wavelength value $\lambda_0 = 540$ nm are expressed by the variables mentioned above, they can be normalized to have the power ϕ_T of the entire lens system at "1" expressed by the following formula:

$$\phi_T = (\phi_a + \phi_b) + (\phi_1 + \phi_2) - \frac{d}{1.49409}(\phi_a\phi_b + \phi_1\phi_2 + \phi_1\phi_2 + \phi_b\phi_1) \tag{2}.$$
$$= 1$$

Next, assuming that the power of the entire lens system 1 at the wavelength $\lambda_1 = 610$ nm is expressed as ϕ_T', the power ϕ_T' of the entire lens system 1 is obtained as follows. The diffraction grating mentioned above has a feature which is represented by the following relation:

$$\frac{\lambda}{\phi} = \text{constant,}$$

wherein λ represents wavelength, and ϕ represents power.

Therefore, the power ϕ_a' of the diffracting surface of the first surface 2 obtained at the wavelength λ_1 can be expressed as follows:

$$\phi'_a = \frac{\lambda_1}{\lambda_0}\phi_a.$$

The power ϕ_b' of the diffracting surface of the second surface 3 likewise can be expressed as follows:

$$\phi'_b = \frac{\lambda_1}{\lambda_0}\phi_b.$$

The power of the refracting optical system, on the other hand, becomes as follows:
The power ϕ_1' of the refracting optical system obtained on the first surface 2 is expressed as follows:

$$\phi'_1 = \frac{n_1 - 1}{r_1} = \frac{n_1 - 1}{n_0 - 1}\phi_1.$$

On the second surface 3, the power ϕ_2' of the refracting optical system becomes as expressed below:

$$\phi'_2 = \frac{1 - n_1}{r_2} = \frac{n_1 - 1}{n_0 - 1}\phi_2.$$

Therefore, the power ϕ_T' of the entire lens system 1 can be expressed as follows:

$$\phi'_T = (\phi'_a + \phi'_b) + (\phi'_1 + \phi'_2) - \frac{d}{n_1}(\phi'_a \phi'_b + \phi'_1 \phi'_2 + \phi'_a \phi'_2 + \phi'_b \phi'_1)$$

$$= \frac{\lambda_1}{\lambda_0}(\phi_a + \phi_b) + \frac{n_1 - 1}{n_0 - 1}(\phi_1 + \phi_2)$$

$$- \frac{d}{n_1}\left\{\frac{\lambda_1^2}{\lambda_0^2}\phi_a \phi_b + \frac{(n_1 - 1)^2}{(n_0 - 1)^2}\phi_1 \phi_2 + \frac{\lambda_1}{\lambda_0} \cdot \frac{n_1 - 1}{n_0 - 1}(\phi_a \phi_2 + \phi_b \phi_1)\right\} \quad \ldots \quad (3).$$

In order to attain the achromatic effect for the wavelengths 540 nm and 610 nm, the respective powers ϕ_T and ϕ_T' of the entire lens system 1 must be made equal to each other. Therefore, from the relation of $\phi_T = \phi_T'$, a first condition formula can be derived as expressed below:

$$\phi'_T - \phi_T = 0 \qquad\qquad (4).$$

The power ϕ_T'' of the entire lens system 1 in the case of occurrence of temperature variations is next obtained. When a temperature change Δt takes place, the linear expansion of the lens system 1 causes the curvature r to change to r" = (1 + $\alpha\Delta t$)r . Meanwhile, the diffracting surface has a phase function $\phi(r_a)$ which is expressed as follows:

$$\phi(r_a) = \frac{\pi r_a^2}{\lambda_0}\phi_a - 2n\pi.$$

Therefore, powers ϕ_a'' and ϕ_b'' of the diffracting surfaces obtained respectively on the first surface 2 and the second surface 3 when the temperature change Δt takes place become respectively as expressed below:

$$\phi''_a = \frac{1}{(1 + \alpha\Delta t)^2}\phi_a, \quad \phi''_b = \frac{1}{(1 + \alpha\Delta t)^2}\phi_b.$$

Further, powers ϕ_1'' and ϕ_2'' of the refracting optical system become respectively as expressed below:

$$\phi''_1 = \frac{n_2 - 1}{r''_1} = \frac{n_2 - 1}{(n_0 - 1)(1 + \alpha\Delta t)}\phi_1, \quad \phi''_2 = \frac{1 - n_2}{r''_2} = \frac{n_2 - 1}{(n_0 - 1)(1 + \alpha\Delta t)}\phi_2.$$

wherein "n_2" represents a refractive index obtained after the change of temperature and is expressed as follows:

$$n_2 = n_0 + \frac{dn}{dt}\Delta t$$

Further, a change in temperature also causes a distance "d" between the first surface 2 and the second surface 3 to change to d" = $(1 + \alpha\Delta t)d$. As a result, the power ϕ_T" of the entire lens system 1 obtained after the change of temperature becomes as expressed below:

$$\phi_T'' = \phi_a'' + \phi_b'' + \phi_1'' + \phi_2'' - \frac{d''}{n_2} (\phi_a'' \phi_b'' + \phi_1'' \phi_2'' + \phi_a'' \phi_2'' + \phi_b'' \phi_1'')$$

$$= \frac{1}{(1+\alpha\Delta t)^2} (\phi_a + \phi_b) + \frac{(n_0 + \frac{dn}{dt}\Delta t - 1)}{(n_0 - 1)(1+\alpha\Delta t)} (\phi_1 + \phi_2)$$

$$- \frac{d(1+\alpha\Delta t)}{n_0 + \frac{dn}{dt}\Delta t} \left\{ \frac{1}{(1+\alpha\Delta t)^4} \phi_a \phi_b + \frac{(n_0 + \frac{dn}{dt}\Delta t - 1)^2}{(n_0 - 1)^2 (1+\alpha\Delta t)^2} \phi_1 \phi_2 \right.$$

$$\left. + \frac{(n_0 + \frac{dn}{dt}\Delta t - 1)}{(n_0 - 1)(1+\alpha\Delta t)^3} (\phi_a \phi_2 + \phi_b \phi_1) \right\} \qquad \dots (5).$$

From the above formula, a second condition formula for eliminating the power fluctuations of the lens system due to temperature variations can be derived as expressed below:

$$\phi''_T - \phi_T = 0 \qquad\qquad\qquad (6).$$

The lens system 1 according to the invention has the above-stated variables ϕ_a, ϕ_b, ϕ_1, ϕ_2 and "d" arranged to be at such values that satisfy the formulas (2), (4) and (6). The arrangement enables the embodiment to attain an achromatic effect at the wavelengths 540 nm and 610 nm with the power of the entire lens system 1 set at "1", so that the lens system 1 can be arranged to have no variation in the entire system power against variations in temperature. Since there are three condition formulas for five variables, a solution cannot be uniquely obtained and thus takes various values. One example of the solution indicates existence of one arrangement whereby no variation of optical characteristics (power) takes place for variations in temperature. In the case of this example, the five variables ϕ_a, ϕ_b, ϕ_1, ϕ_2 and "d" are set as follows: $\phi_a = -0.0194024$, $\phi_b = 0.4925936$, $\phi_1 = 1.1402412$, $\phi_2 = 1.3370397$ and d = 1.4210498. Fig. 2 shows the power variations obtained in this case in relation to variations in wavelength. As shown in Fig. 2, the power varies less than ±0.1% throughout the entire visible spectrum from 400 nm to 700 nm to indicate that an achromatic effect (achromatism) is adequately attained. Fig. 3 shows the variations of power obtained, in the case of the above-stated example, in relation to temperature variations. As apparent from Fig. 3, the power variations are corrected down to a rate less than 0.005% within a range of temperature variations ±30 degrees to indicate also an adequate performance.

In accordance with the invention, a diffracting optical element which forms the diffracting surface is not required to be in any special shape. Therefore, a Fresnel-type diffraction grating having a known saw-tooth-like grooved shape or a diffraction grating of a binary type having a stepped grooved shape can be employed as the diffracting optical element. In manufacturing the lens system, the diffracting optical element may be formed either directly on the base material of a refracting lens or formed on a refracting surface after a photosensitive polymer or the like is thinly applied to the refracting surface.

While the embodiment is described above by way of example as arranged to have two diffracting surfaces, the invention can be carried out for a lens system having at least one diffracting surface. In that case, the lens system can be more easily manufactured at a lower cost as its structural arrangement becomes simpler to dispense with a process for optical axis adjustment between the diffracting surfaces. Fig. 4 shows a lens system arranged to have such a simpler structural arrangement as a second embodiment of the invention. In Fig. 4, all elements that are identical to those shown in Fig. 1 are indicated by the same reference numerals. Referring to Fig. 4, a surface 5 has only a refracting sur-

face and has no diffracting surface there. Fig. 5 shows variations in power taking place in the second embodiment in relation to wavelength variations. Fig. 6 shows power variations taking place in the second embodiment in relation to temperature variations. The variables of the elements of the second embodiment are set as follows: $\phi_a = 0.0440682$, $\phi_b = 0$, $\phi_1 = 1.4115329$, $\phi_2 = 1.4928773$ and $d = 1.3396948$. As apparent from Figs. 5 and 6, although the amounts of variations are greater than in the first embodiment shown in Fig. 1, the second embodiment is capable of sufficiently correcting both the chromatic aberration and the power variations due to temperature variations.

The second embodiment shown in Fig. 4 may be modified to remove the diffracting surface from the first surface 1 and to have a diffracting surface formed on the second surface 5.

In the case of each of the embodiments described above, the invention is applied to a single lens. However, the invention is not limited to single lenses but is of course applicable to a lens system in which at least one of diffracting and refracting optical systems is composed of a plurality of lenses. In that case, the lens system can be adequately arranged by first obtaining the amounts of power variations in relation to both wavelength and temperature variations for each of surfaces and, after that, by arranging the overall power of the entire lens system to be constant.

In each of the embodiments described above, the optical characteristics, such as the focal length and the focus position (focal point), of the lens system are arranged to be unvarying by adjusting the lens system only. However, since the lens system is supported by a lens barrel in actuality, the lens system can be arranged to have its overall optical characteristic unvarying by taking into consideration also the expansion and the contraction of the lens barrel anticipated to be caused by variations in temperature.

According to the arrangement of each of the embodiments described above, not only the optical characteristics such as a focal length and a focus position can be arranged to be unvarying against temperature variations but also an achromatic effect can be attained for a desired wavelength region. Further, since a plastic lens is usable without necessitating use of any additional mechanism such as a temperature sensor, the lens system can be manufactured at a low cost. The arrangement for combining the diffracting optical system and the refracting optical system with each other effectively permits enhancement in performance and reduction in number of lenses to be included.

In the case of each of the embodiments described above, the optical characteristics to be compensated for variations are described to be paraxial powers, i.e., the focal length and the focus position (focal point), of the lens system. In accordance with the invention, however, the optical characteristics to be compensated for variations are not limited to these characteristics but may include, for example, also a spherical aberration. In cases where the spherical aberration is to be compensated for its variations, an optical system can be arranged to have its spherical aberration unvarying against wavelength and temperature variations by deriving, from marginal rays of light other than on-axial rays of light, some formulas corresponding to the formulas (2), (4) and (6) disclosed in the foregoing and by obtaining a solution from these formulas. Further, according to the invention, it is also possible to include both the spherical aberration and the paraxial powers (the focal length and the focus position) in the optical characteristics to be compensated.

The lens system in each of the embodiments described above has only the refracting optical system besides the diffracting optical system. However, the invention applies also to a lens system having a reflecting optical system such as a plane mirror, a concave mirror or the like in addition to the above-stated optical systems.

While a plastic lens is used in each of the embodiments described above, the invention is applicable to a lens system composed of a mixture of a plastic lens and a glass lens and also to a lens system composed of a glass lens of a large coefficient of thermal expansion.

Since the lens system in each of the embodiments described above can be manufactured at a low cost and yet has a high performance, the lens system is highly suited for the image forming optical system of optical apparatuses such as an interchangeable lens, a camera, a copying apparatus, a projector, etc. Further, a lens system designed on the basis of the spirit and principle of the invention is applicable to the image forming optical system of optical apparatuses other than the optical apparatuses mentioned above, such as a microscope, a binocular, a telescope, a semiconductor-device manufacturing exposure device, an optical recording/reproducing apparatus, etc.

According to the arrangement of each of the embodiments described above, a lens system which is capable of keeping its optical characteristics substantially unvarying against temperature variations within a predetermined range of variations and also attaining an achromatic effect within a predetermined region of wavelengths can be arranged to have a high rate of performance. In accordance with the invention, therefore, a lens system and an optical apparatus using the lens system can be arranged to excel in performance.

In a lens system having one or a plurality of diffracting surfaces and one or a plurality of refracting surfaces, a power of each surface and a distance between the surfaces are set such that an optical characteristic of the lens system, such as a focal length (focal point) and/or a spherical aberration, remains substantially unvarying relative to temperature variations within a predetermined range and that an achromatic effect is substantially attained for the focal length (focal point) and/or the spherical aberration within a predetermined region of wavelength.

Claims

1. A lens system having one or a plurality of diffracting surfaces and one or a plurality of refracting surfaces, in which a power of each surface and a distance between the surfaces are set such that an optical characteristic of said lens system remains substantially unvarying relative to temperature variations within a predetermined range and that an achromatic effect is substantially attained for the optical characteristic within a predetermined region of wavelength.

2. A lens system according to claim 1, wherein the optical characteristic includes a focal length (focus position) and/or an amount of spherical aberration.

3. A lens system according to claim 1, wherein a power of each surface and a distance between the surfaces are set such that the optical characteristic remains substantially unvarying relative to temperature variations within the predetermined range, by taking into consideration the deformation of at least one surface and a change of at least one distance between the surfaces caused by the temperature variations within the predetermined range.

4. A lens system according to claim 1, wherein a power of each surface and a distance between the surfaces are set such that the optical characteristic remains substantially unvarying relative to temperature variations within the predetermined range, by taking into consideration the deformation of a plurality of surfaces and a change of a plurality of distances between the surfaces caused by the temperature variations within the predetermined range.

5. A lens system according to claim 1, wherein a power of each surface and a distance between the surfaces are set such that the optical characteristic remains substantially unvarying relative to temperature variations within the predetermined range, by taking into consideration the expansion and contraction of a lens barrel caused by the temperature variations within the predetermined range.

6. A lens system according to claim 1, wherein said diffracting surface has a diffraction grating which is in a saw-tooth-like sectional shape.

7. A lens system according to claim 1, wherein said diffracting surface has a diffraction grating which is in a stepped sectional shape.

8. A lens system according to claim 1, wherein said lens system includes a lens having said diffracting surface and said refracting surface formed as a common surface.

9. A lens system according to claim 8, wherein said lens is a single lens having both said diffracting surface and said refracting surface formed on one surface thereof and only said refracting surface formed on the other surface thereof.

10. A lens system according to claim 8, wherein said lens is a single lens having both said diffracting surface and said refracting surface formed on one surface thereof and both said diffracting surface and said refracting surface formed on the other surface thereof.

11. A lens system according to claim 1, wherein said lens system includes a first lens having said diffracting surface and a second lens having said refracting surface.

12. A lens system according to claim 11, wherein said first lens has also said refracting surface besides said diffracting surface.

13. A lens system according to claim 12, wherein said second lens has also said diffracting surface besides said refracting surface.

14. A lens system according to claim 13, wherein at least one of said first lens and said second lens is a lens having said diffracting surface and said refracting surface formed as a common surface.

15. A lens system having one or a plurality of diffracting surfaces and one or a plurality of refracting surfaces, in which a power of each surface and a distance between the surfaces are set such that an optical characteristic of said lens system remains the same at two different temperatures and that the optical characteristic remains the same at two different wavelengths.

16. A lens system according to claim 15, wherein the optical characteristic of said lens system includes a focal length (focal point) and/or an amount of spherical aberration of said lens system.

17. A lens system according to claim 16, wherein a power of each surface and a distance between the surfaces are set such that the focal length remains the same at the two different temperatures, by taking into consideration the deformation of at least one surface and a change of at least one distance between the surfaces caused by temperature variations between the two different temperatures.

18. A lens system according to claim 16, wherein a power of each surface and a distance between the surfaces are set such that the focal length remains the same at the two different temperatures, by taking into consideration the deformation of a plurality of surfaces and a change of a plurality of distances between the surfaces caused by temperature variations between the two different temperatures.

19. A lens system according to claim 16, wherein a power of each surface and a distance between the surfaces are set such that the focal length remains the same at the two different temperatures, by taking into consideration the expansion and contraction of a lens barrel caused by temperature variations between the two different temperatures.

20. A lens system according to claim 15, wherein said diffracting surface has a diffraction grating which is in a saw-tooth-like sectional shape.

21. A lens system according to claim 15, wherein said diffracting surface has a diffraction grating which is in a stepped sectional shape.

22. A lens system according to claim 15, wherein said lens system includes a lens having said diffracting surface and said refracting surface formed as a common surface.

23. A lens system according to claim 22, wherein said lens is a single lens having both said diffracting surface and said refracting surface formed on one surface thereof and only said refracting surface formed on the other surface thereof.

24. A lens system according to claim 22, wherein said lens is a single lens having both said diffracting surface and said refracting surface formed on one surface thereof and both said diffracting surface and said refracting surface formed on the other surface thereof.

25. A lens system according to claim 15, wherein said lens system includes a first lens having said diffracting surface and a second lens having said refracting surface.

26. A lens system according to claim 25, wherein said first lens has said refracting surface besides said diffracting surface.

27. A lens system according to claim 26, wherein said second lens has said diffracting surface besides said refracting surface.

28. A lens system according to claim 27, wherein at least one of said first lens and said second lens is a lens having said diffracting surface and said refracting surface formed as a common surface.

29. A lens system according to claim 1, wherein said lens system includes one or a plurality of plastic lenses.

30. A lens system according to claim 29, wherein said plastic lens has said diffracting surface.

31. A lens system according to claim 29, wherein said plastic lens has said refracting surface.

32. A lens system according to one of claims 1 to 31, wherein said lens system has a positive power as a whole.

33. An optical apparatus comprising a lens system according to claim 32 and means for holding a photosensitive body, wherein an image of an object is formed by said lens system on said photosensitive body.

34. An optical apparatus according to claim 33, wherein said optical apparatus is a camera.

35. An optical apparatus according to claim 33, wherein said optical apparatus is a copying apparatus.

36. An optical apparatus according to claim 33, wherein said optical apparatus is a semiconductor-device-manufacturing exposure device.

37. An optical apparatus comprising a lens system according to claim 32, wherein an image of an object to be observed is projected by said lens system.

38. An optical apparatus according to claim 37, wherein said optical apparatus is a microscope.

39. An optical apparatus according to claim 37, wherein said optical apparatus is a projector.

40. An optical apparatus according to claim 37, wherein said optical apparatus is one of a binocular and a telescope.

41. An optical apparatus according to claim 37, wherein said optical apparatus is an optical recording/reproducing apparatus.
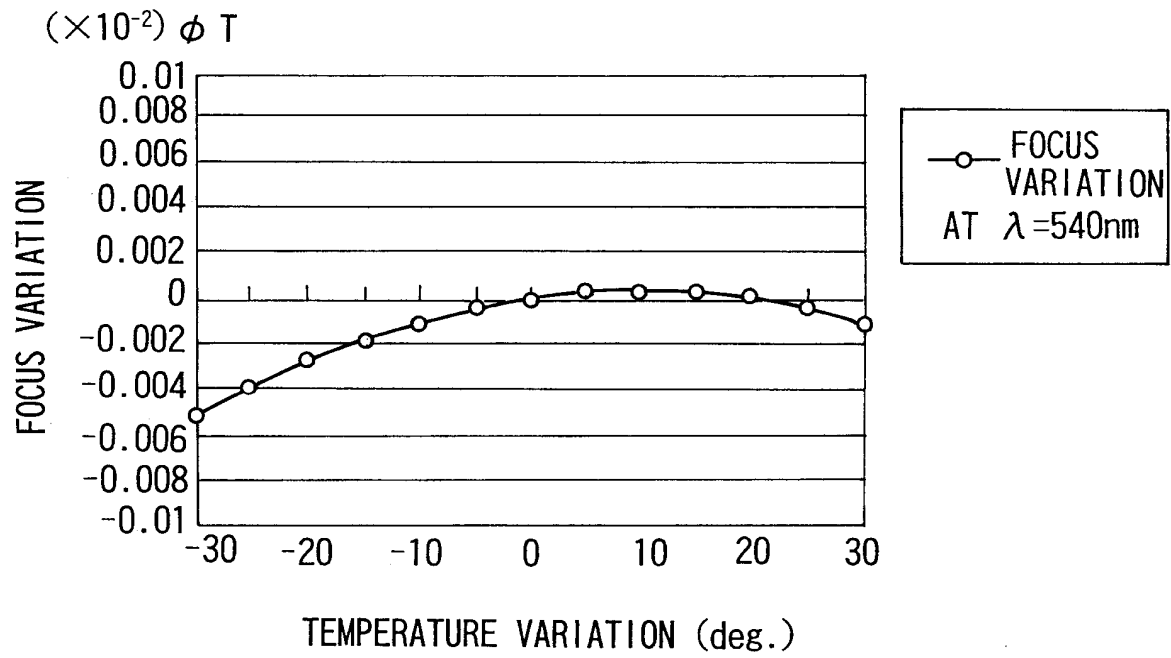
FIG. 1
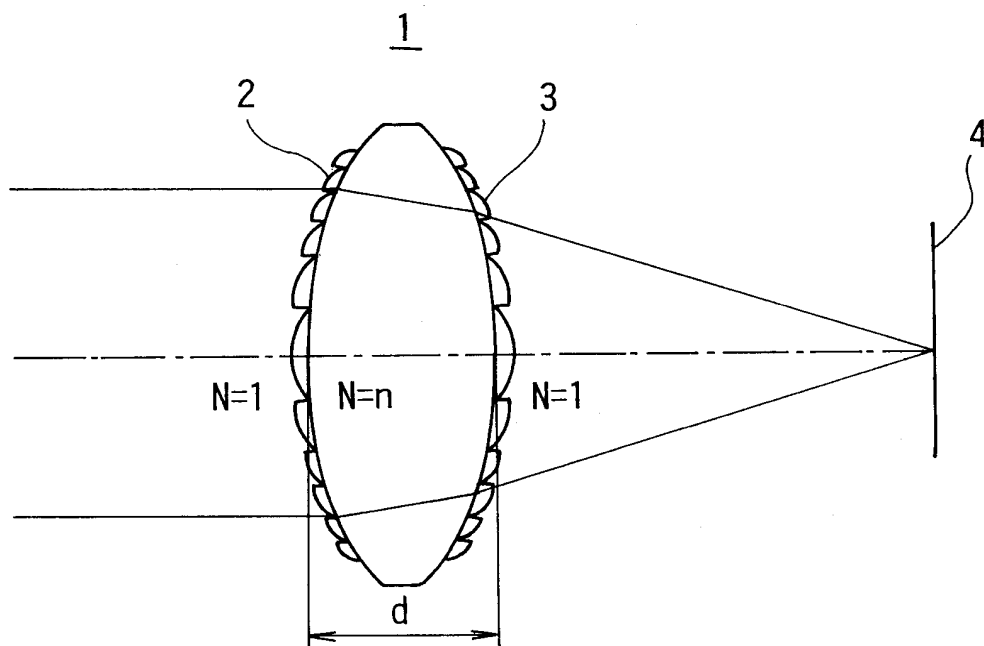
FIG. 2
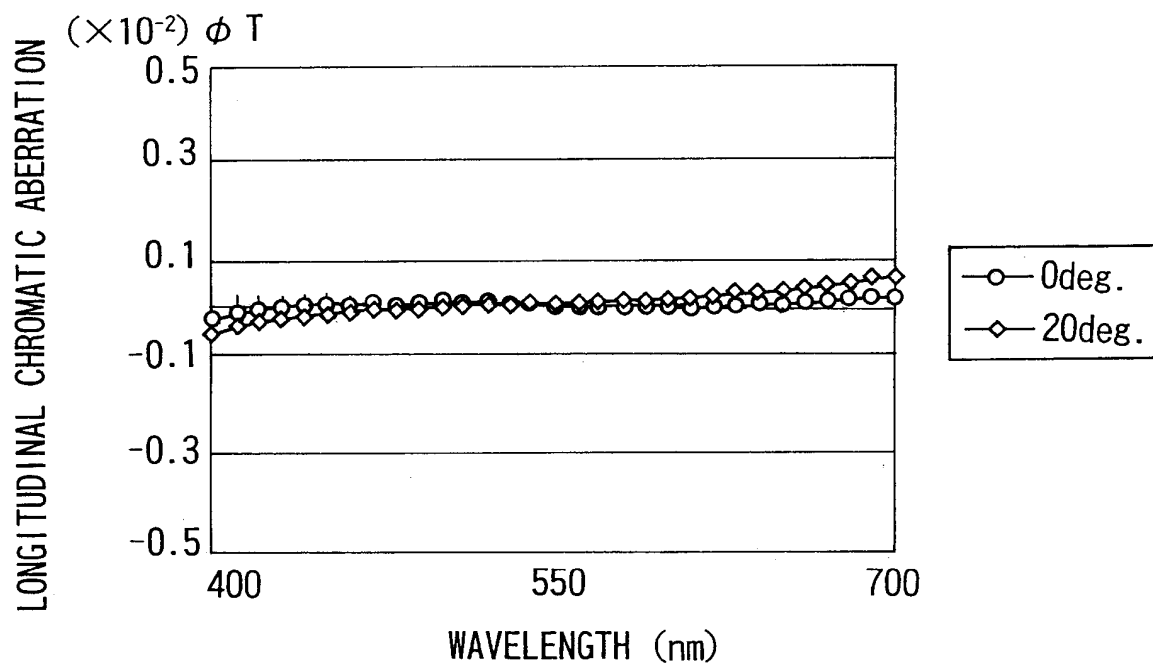
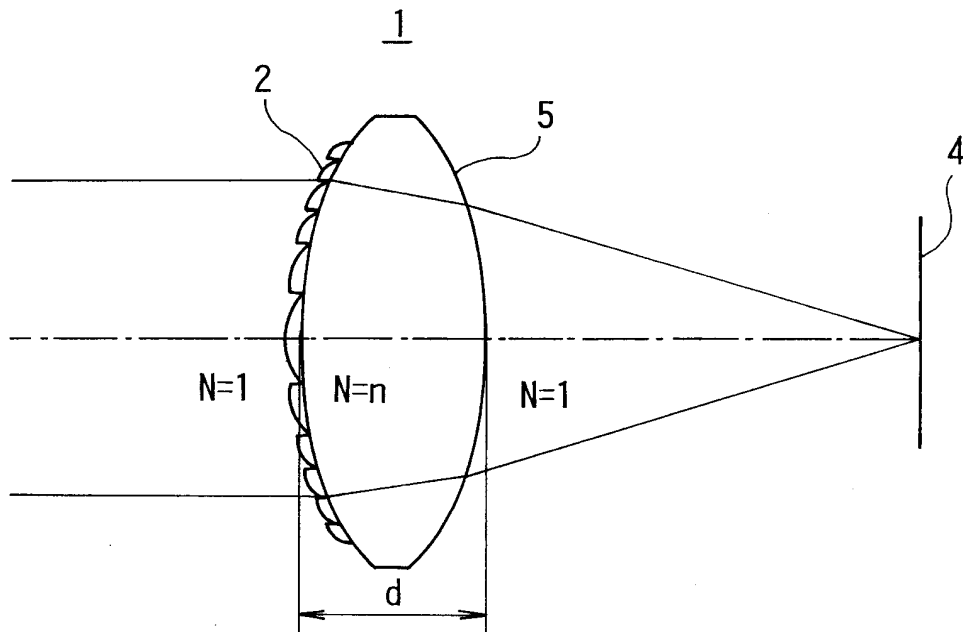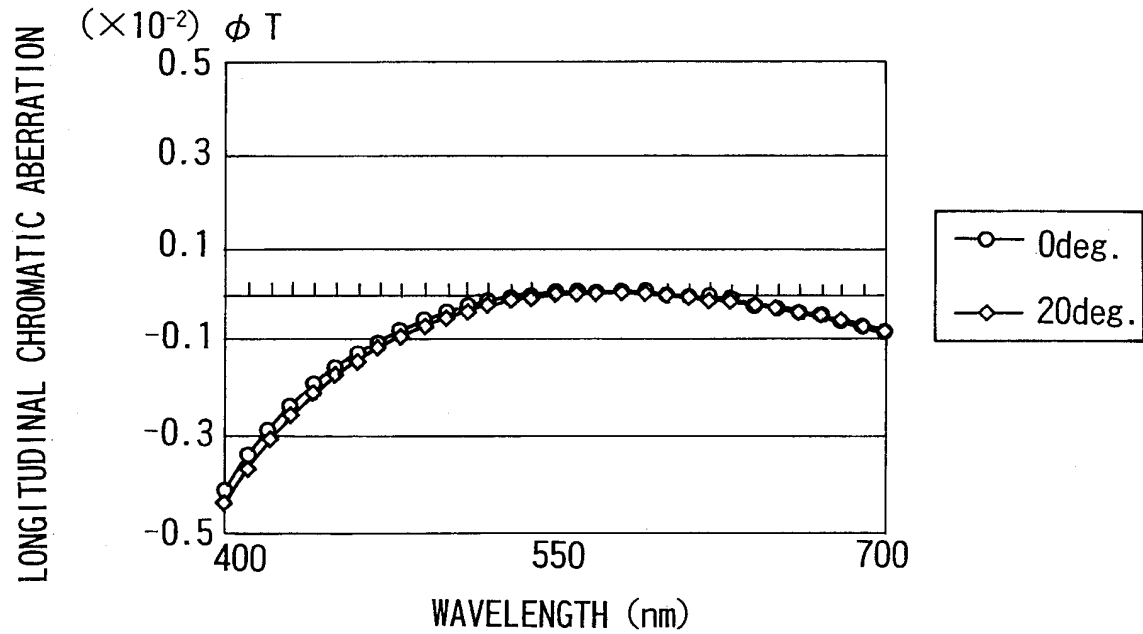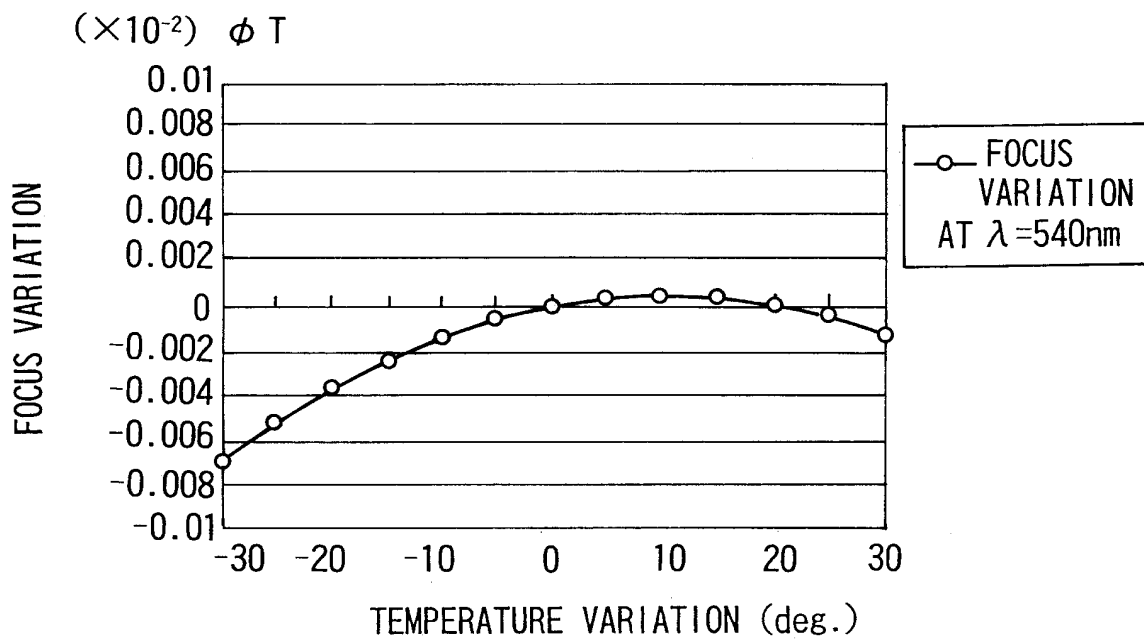# FIG. 3

FIG. 4

FIG. 5

FIG. 6

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 97 11 8735

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	US 5 504 628 A (BORCHARD JOSEPH F) 2 April 1996 * the whole document *	1-5, 8-19, 22-28, 32,33,37	G02B5/18 G02B27/00
X	US 5 543 966 A (MEYERS MARK M) 6 August 1996 * abstract; figures 1-5 * * column 2, line 37 - column 3, line 21 * * column 4, line 35 - column 5, line 23 * * column 5, line 50 - column 6, line 23 * * column 14, line 49 - line 62 * * column 17, line 61 - column 18, line 5 *	1-10, 15-24, 29-41	
A	EP 0 517 409 A (HUGHES AIRCRAFT CO) 9 December 1992 * abstract; figures 1-3,8,13 *	1,15,33, 37	
E	US 5 691 847 A (CHEN CHUNGTE W) 25 November 1997 * the whole document *	1-5, 8-19, 22-28, 32,33,37	TECHNICAL FIELDS SEARCHED (Int.Cl.6) G02B
X,P	EP 0 758 753 A (EASTMAN KODAK CO) 19 February 1997 * abstract; figures 1,2 * * page 2, line 25 - line 53 *	1-10, 15-24, 29-33,37	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	4 February 1998	Jakober, F

EPO FORM 1503 03 82 (P04C01)